

Comparative Performance Evaluation of Well Control Methods for Onshore Vertical Oil Wells: A Case Study of Exploration Well 6P2-59, Sirte Basin, Libya

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بحوض سرت في ليبيا P2-596 مقارنة تقييم الأداء لطرق التحكم في ابار النفط الرأسية:
دراسة حالة لبئر الاستكشاف

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Abstract

Well control operations represent the technical cornerstone for human safety, environmental integrity, and asset protection in oil and gas drilling operations. This research presents comprehensive hydraulic, geological, and operational evaluation comparing two primary well control techniques, The Driller's Method (DM) and the Wait & Weight Method (W&W) for circulating out a kick and restoring the primary well barrier. The mathematical modeling and hydraulic simulations are applied to the onshore vertical exploration well 6P2-59 (E.6P1-59 Deep Pool Test), located in Concession 59A near the Harash field within the Sirte Basin, Libya. Following shut-in procedures, stabilized surface readings recorded a Shut-In Drill Pipe Pressure (SIDPP) of 1,610 psi, a Shut-In Casing Pressure (SICP) of 1,920 psi, and a pit gain (influx volume) of 25 bbl at a Total Vertical Depth (TVD) of 10,000 ft. The required Kill Mud Weight (KMW) was calculated at 13.10 ppg (adjusted to 13.20 ppg with a 0.10 ppg operational safety margin), compared to the original mud weight of 10.0 ppg. Initial Circulating Pressure (ICP) and Final Circulating Pressure (FCP) were established at 1,950 psi and 449 psi, respectively, with a pressure step-down rate of 111 psi per 100 strokes.

This study provides a technical comparison regarding dynamic casing shoe stress, potential underground blowout risks, equipment exposure times, and operational complexities between both methods, serving as a critical reference for deep exploration drilling in high-pressure sedimentary regimes.

Keywords: Well Control, Primary Barrier, Driller's Method, Wait & Weight Method, Kill Sheet, Sirte Basin, Well 6P2-59, Oil-Based Mud vs. Water-Based Mud.

المخلص

تمثل عمليات السيطرة على الآبار الركيزة الفنية الأساسية لضمان سلامة الأفراد، وحماية البيئة، والحفاظ على الأصول في عمليات حفر آبار النفط والغاز. يقدم هذا البحث تقييمًا هيدروليكيًا وجيولوجيًا وتشغيليًا شاملاً يقارن بين طريقتين أساسيتين للسيطرة على الآبار، وهما "طريقة الحفار (Driller's Method)" و"طريقة الانتظار والوزن (Wait & Weight Method)"، لإزالة الرافعة واستعادة كفاءة حاجز الأمان الأولي. وقد تم تطبيق النمذجة الرياضية والمحاكاة الهيدروليكية على البئر الاستكشافي العمودي البري 6P2-59 اختبار الحوض العميق (E.6P1-59)، الواقع في الامتياز A 59 بالقرب من حقل الهروش بحوض سرت، ليبيا.

وعقب إجراءات الإغلاق، سجلت القراءات السطحية المستقرة ضغط إغلاق أنابيب الحفر (SIDPP) بقيمة 1,610 رطل/بوصة مربعة، وضغط إغلاق غلاف البئر (SICP) بقيمة 1,920 رطل/بوصة مربعة، وزيادة في حجم خزان الطين (حجم التدفق) قدرها 25 برميلًا عند عمق رأسي إجمالي (TVD) يبلغ 10,000 قدم. وبناءً على ذلك، تم حساب وزن طين القتل المطلوب (KMW) عند 13.10 رطل/جالون (والذي تم تعديله إلى 13.20 رطل/جالون بإضافة هامش أمان تشغيلي قدره 0.10 رطل/جالون)، مقارنة بكثافة الطين الأصلي البالغة 10.0 رطل/جالون. كما أُسست قياسات ضغط التدوير الأولي (ICP) وضغط التدوير النهائي (FCP) عند 1,950 و 449 رطل/بوصة مربعة على التوالي، بمعدل انخفاض للضغط يبلغ 111 رطل/بوصة مربعة لكل 100 ضخة. تقدم هذه الدراسة مقارنة فنية شاملة تتناول الإجهاد الديناميكي الواقع على حذاء التبتطين، ومخاطر الفوران الداخلي المحتملة، وزمن تعرض المعدات للضغوط العالية، والتعقيدات التشغيلية لكلتا الطريقتين، لتكون بمثابة مرجع فني اعتمادي لعمليات الحفر الاستكشافي العميق في الطبقات الرسوبية ذات الضغوط العالي.

الكلمات المفتاحية: السيطرة على الآبار، الحاجز الأساسي، طريقة الحفار، طريقة الانتظار والوزن، ورقة حسابات قتل البئر، حوض سرت، طين الحفر ذو الأساس الزيتي، طين الحفر ذو الأساس المائي.

1. Introduction

The foundational principles of modern well control were established by Goins and O'Brien (1960) [1]. and further formalized by (Bourgoyne 1986) [2], who demonstrated that maintaining a constant bottom-hole pressure slightly above formation pore pressure is critical to preventing secondary influxes while circulating out gas kicks. Their work classified the Driller's Method (DM) and the Wait & Weight Method (W&W) as the primary primary-barrier restoration techniques. While the Driller's Method simplifies operational execution by separating influx removal from kill mud displacement, early research highlighted that it subjects surface equipment and the casing shoe to prolonged elevated pressures.

(Grace, 2003) [3] and (Adams & Kuhlman, 2012) [4] were conducted comprehensive hydraulic comparative studies evaluating dynamic casing pressure behaviors during kick circulation. Their findings revealed that in deep exploration wells with small annular clearances, the Wait & Weight Method significantly reduces peak pressure at the casing shoe compared to the Driller's Method. This reduction occurs because the heavy kill mud enters the annulus while the gas influx is still below or near the shoe, providing additional hydrostatic head that suppresses peak casing pressures (SICP). Conversely, Santos et al. (2015) emphasized that the operational success of the Wait & Weight Method relies heavily on surface barite mixing capacity; if mixing is delayed, gas expansion in the annulus can lead to rapid pressure buildup and potential formation breakdown.[5]

This study will carry a comparative performance evaluation for well control methods for onshore vertical oil well.

1.1 Well Integrity & Dual-Barrier Concept

Maintaining wellbore stability requires keeping the equivalent mud weight within the safe drilling window bound by the formation pore pressure gradient and the formation fracture gradient. Well integrity relies on a strict dual-barrier system:

This study will carry out a comparative performance evaluation for well casing methods for vertical oil well . [6]

- **Primary Well Barrier:** The hydrostatic fluid column of drilling mud. Its primary role is to exert sufficient hydrostatic pressure (P_h) to counterbalance formation pore pressure (P_{pore}) and prevent fluid influx.
- **Secondary Well Barrier:** The physical containment envelope activated upon primary barrier failure. It consists of the Blowout Preventer (BOP) stack, casing strings, wellhead components, high-pressure line valves (HCR), and the cement sheath, Figure (1) shows

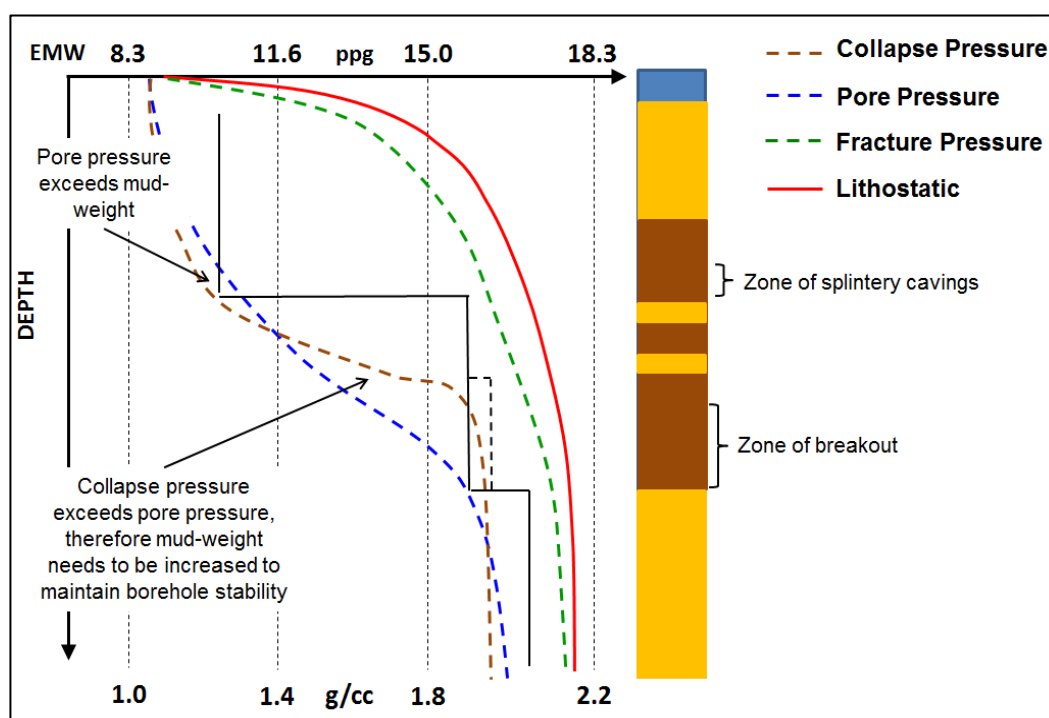


Figure (1): Mud drilling window [7]

If hydrostatic pressure drops below pore pressure, formation fluids enter the wellbore, creating a kick. Uncontrolled influx expansion can escalate into a surface blowout.

Common causes of kicks include inadequate mud density, improper hole fill-up during tripping, swabbing effects, gas-cut mud, or severe lost circulation. This study models kill operations for exploration well 6P2-59 and compares the operational performance of the Driller's Method versus the Wait & Weight Method.

2. Case Study & Well Data (Well 6P2-59)

2.1 Geological & Location Setting

Exploration well **6P2-59 (E.6P1-59)** is located in **Concession 59A** in the Sirte Basin, Libya, approximately 9.6 km southwest of the Harash field and 3.7 km southeast of well 6P1-59. The

well was drilled as a deeper pool exploration test targeting structural-cum-stratigraphic traps within the 6P High horst block, As shown in figure (2)

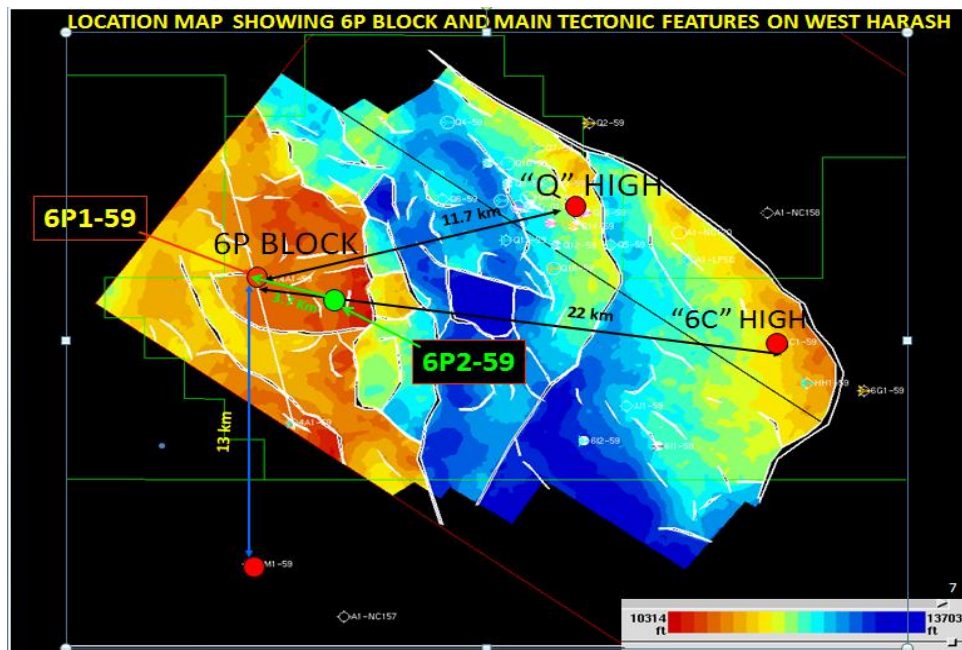


Figure (2): Well Location Map [1]

To accurately simulate well control hydraulics and perform comparative calculations between the Driller's Method and the Wait & Weight Method for exploration well 6P2-59, the key geological, mechanical, and operational parameters were established whereas, Table (1) summarizes the baseline wellbore geometry, casing specifications, fluid properties, formation strength gradients, and stabilized surface shut-in data recorded following the kick event.

Table (1): Geological, Mechanical, and Fluid Parameters for Well 6P2-59

Parameter Category	Technical Description	Value	Unit
Geological / Mechanical	Total Vertical Depth (TVD)	10,000	ft
	Casing Shoe Depth	6,800	ft
	Casing Outer / Inner Diameter	9.625 / 8.835	in
	Casing Grade & Weight	K55, 40	lb/ft
	Open Hole Size	8.50	in
Fluid & Pressure	Original Mud Weight (OMW)	10.0	ppg
	Original Mud Hydrostatic Gradient	0.520	psi/ft
	Formation Strength Gradient	0.850	psi/ft
	Shut-In Drill Pipe Pressure (SIDPP)	1,610	psi
	Shut-In Casing Pressure (SICP)	1,920	psi
	Influx Volume (Pit Gain)	25	bbl
Rig Pump Parameters	Pump Displacement Output (P_o)	0.119	bbl/stk
	Slow Circulating Rate (SCR)	30	SPM
	Slow Circulating Rate Pressure (P_L)	340	psi

3.2 Drill String Specifications

The physical dimensions and volumetric capacity of the drill string components are critical parameters for calculating internal pipe volume, determining surface-to-bit stroke requirements, and estimating mud displacement timing during well control operations. Shows the Table (2) details of outer and inner diameters, section lengths, and unit internal capacities for the Drill Pipe (DP), Heavy Weight Drill Pipe (HWDP), and Drill Collars (DC) comprising the drill assembly in well 6P2-59

Table (2): Drill String Component Specifications and Capacity Data

String Component	Outer Diameter (OD)	Inner Diameter (ID)	Length (L)	Capacity (C)
Drill Pipe (DP)	5.000 in	4.276 in	8,300 ft	0.01776 bbl/ft
Heavy Weight Drill Pipe (HWDP)	5.000 in	3.000 in	1,100 ft	0.00874 bbl/ft
Drill Collars (DC)	6.375 in	2.813 in	600 ft	0.00768 bbl/ft

4. Methodology & Well Control Hydraulic Calculations

To quantify the hydrostatic and dynamic pressure parameters required for circulating out the kick and restoring the primary well barrier, fundamental well control calculations were performed using the stabilized shut-in data whereas, Table (3) outlines the governing mathematical formulas, calculated values, and operational remarks for formation pore pressure, kill mud density, circulating pressure limits, and the drill pipe pressure step-down rate for exploration well 6P2-59.

Table (3): Governing Equations & Well Control Calculations

Parameter / Variable	Mathematical Formula	Calculated Value	Remarks / Notes
Formation Pore Pressure (P_{pore})	$P_{pore} = SIDPP + (0.052 \times OMW \times TVD)$	6,810 psi	—
Theoretical Kill Mud Weight (KMW)	$KMW = OMW + \left(\frac{SIDPP}{0.052 \times TVD} \right)$	13.10 ppg	Exact value: 13.096 ppg
Final Kill Mud Weight (KMW_{final})	$KMW_{final} = KMW + SM$	13.20 ppg	Includes 0.10 ppg Safety Margin (SM)
Initial Circulating Pressure (ICP)	$ICP = SIDPP + SCRP$	1,950 psi	1,610 + 340 psi
Final Circulating Pressure (FCP)	$FCP = SCRP \times \left(\frac{KMW}{OMW} \right)$	449 psi	$340 \times \left(\frac{13.20}{10.0} \right) = 448.8$ psi

Pressure Drop Rate (ΔP_{100})	$\frac{\Delta P_{100}}{(ICP - FCP) \times 100} = \frac{111 \text{ psi}}{N_{DP} / 100 \text{ stks}}$	111 psi /100 stks	Pressure decreases per 100 strokes
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Table (4) indicates the volumetric capacity calculations for the internal drill string, annulus, and total fluid system of well 6P2-59.

Table (4): Wellbore Capacities & Volumes

Section / Component	Mathematical Calculation	Volume (bbl)
1. Internal Drill String Volume		
- Drill Pipe (DP)	$8,300 \text{ ft} \times 0.01776 \text{ bbl/ft}$	147.42
- Heavy Weight Drill Pipe (HWDP)	$1,100 \text{ ft} \times 0.00874 \text{ bbl/ft}$	9.62
- Drill Collars (DC)	$600 \text{ ft} \times 0.00768 \text{ bbl/ft}$	4.61
Total Internal String Volume (V_{string})	$147.42 + 9.62 + 4.61$	161.65
2. Annular Volume		
- DC to Open Hole (V_{DC-OH})	$600 \text{ ft} \times 0.03071 \text{ bbl/ft}$	18.42
- DP/HWDP to Open Hole (V_{DP-OH})	$2,600 \text{ ft} \times 0.04590 \text{ bbl/ft}$	119.34
- Total Open Hole Annulus ($V_{OH,Ann}$)	$18.42 + 119.34$	137.77
- DP to Casing Annulus (V_{DP-Csg})	$6,800 \text{ ft} \times 0.05154 \text{ bbl/ft}$	350.48
Total Annular Volume ($V_{Annulus}$)	$137.77 + 350.48$	488.25
Total System Volume (V_{Total})	$V_{string} + V_{Annulus}$	649.90

Table (5) presents the required pump strokes and corresponding operational times for each circulation stage in well 6P2-59 at a pump displacement of 0.119 bbl/stk and a slow circulating rate of 30 SPM.

Table (5): Stroke Metrics & Operational Time

Operational Stage	Formula	Strokes	Time (Minutes)	Time (Hours)
Surface to Bit	$N_{DP} = \frac{V_{string}}{P_o}$	1,358	45.28 min	0.75 hr
Bit to Surface	$N_{Ann} = \frac{V_{Annulus}}{P_o}$	4,103	136.77 min	2.28 hrs
Total Wellbore Circulation	$N_{Total} = \frac{V_{Total}}{P_o}$	5,461	182.00 min	3.03 hrs

Where Table (6) shows the drill pipe pressure step-down schedule during kill mud displacement from surface to bit using the Wait & Weight Method for well 6P2-59.

Table (6): Drill Pipe Pressure Step-Down Schedule — Wait & Weight Method

Pump Strokes (stks)	Dynamic Drill Pipe Pressure (psi)	Operational Stage / Milestone
0	1,950 (ICP)	Start pumping kill mud into drill string
100	1,839	Linear step-down phase
300	1,618	Linear step-down phase
500	1,396	Linear step-down phase
700	1,174	Linear step-down phase
900	953	Linear step-down phase
1,100	731	Linear step-down phase
1,300	510	Kill mud approaching drill bit
1,358	449 (FCP)	Kill mud reaches drill bit
1,500 – 5,461	449 (FCP)	Hold FCP constant until kill mud reaches surface

5. Comparative Operational Analysis & Discussion

This section evaluates and interprets the hydraulic simulation results and operational metrics calculated for onshore exploration 6P2-59. While theoretical calculations establish the mathematical boundaries for both the Driller's Method and the Wait & Weight Method, selecting the optimal well control technique requires a detailed trade-off analysis balancing wellbore stability, dynamic pressure exposure, and surface equipment integrity. The following discussion compares both methods across key operational dimensions, including total circulation time, peak dynamic casing shoe stress, risk of underground blowout, and mechanical wear on surface choke manifolds, providing a practical framework for risk mitigation during deep drilling operations in high-pressure sedimentary regimes.

Table (7) presents a comprehensive technical trade-off matrix comparing operational performance, pressure limits, and equipment exposure between the Driller's Method and the Wait & Weight Method for well 6P2-5.

Table (7): Technical Trade-Off Matrix: Driller's vs. Wait & Weight Method

Comparison Aspect	Driller's Method (DM)	Wait & Weight Method (W&W)
Circulation Cycles	Two Full Circulations: Cycle 1 flushes influx; Cycle 2 displaces original mud with kill mud.	One Full Circulation: Simultaneously pumps kill mud while removing influx.
Total Circulation Strokes	$2 \times 5,461 = 10,922$ strokes.	5,461 strokes.
Total Operational Time	≈ 364.0 minutes (6.07 hours).	≈ 182.0 minutes (3.03 hours) (~33% time savings).
Peak Casing Shoe Stress	Higher: Casing shoe is subjected to high surface choke pressures while unweighted mud remains in annulus.	Lower: Heavier kill mud entering the annulus behind gas influx reduces peak shoe pressure.

Surface Equipment Wear	High: Extended circulation increases risk of choke line and valve erosion/washout.	Low: Reduced pumping time minimizes erosion of choke manifolds.
Operational Complexity	Low: Simple execution; choke is adjusted to keep DP pressure constant during 1st circulation.	High: Requires strict adherence to a drill pipe pressure step-down schedule.
Mud Plant Requirement	Can begin immediately using existing pit mud.	Requires weighing up pit volume to 13.20 ppg prior to circulation.

5.2 Dynamic Casing Shoe Integrity & Underground Blowout Evaluation

The weakest point in the active wellbore during well control is the formation immediately below the casing shoe (6,800 ft TVD).

Formation Strength Constraint:

- Formation Strength Gradient = 0.850 psi/ft.
- Maximum Allowable Formation Pressure at Casing Shoe ($P_{shoe,max}$):

$$P_{shoe,max} = 0.850 \text{ psi/ft} \times 6,800 \text{ ft} = 5,780 \text{ psi}$$
- Maximum Allowable Annular Surface Pressure (MAASP) under original mud (10.0 ppg):

$$MAASP = (0.850 - 0.520) \times 6,800 \text{ ft} = 2,244 \text{ psi}$$

During the Driller's Method, as the gas influx migrates up to 6,800 ft, gas expansion increases the casing pressure. If surface casing pressure exceeds MAASP (2,244 psi), formation breakdown at the shoe will occur, potentially leading to an underground blowout.

Conversely, under the Wait & Weight Method, as kill mud (13.20 ppg) moves past the bit and ascends into the open hole, it provides an additional hydrostatic column below the gas kick, reducing peak casing shoe pressure and lowering the risk of formation fracturing.

6. Conclusions & Recommendations

these conclusions and recommendations aim to safeguard well integrity, ensure crew safety, and optimize equipment performance during deep exploration drilling operations in high-pressure sedimentary regimes.

6.1 Conclusions

1. Restoring primary well barrier control for exploration well 6P2-59 requires increasing mud density from 10.0 ppg to a Kill Mud Weight of 13.20 ppg (including a 0.10 ppg safety margin).
2. Displacing the internal drill string requires 1,358 strokes (45.28 minutes), while complete wellbore displacement requires 5,461 strokes (182.0 minutes) at 30 SPM.
3. The Wait & Weight Method is technically superior for Well 6P2-59, reducing total operational time by over 3 hours and reducing peak dynamic casing shoe pressures, provided weighting facilities can supply 13.20 ppg mud without delay.
4. The Driller's Method remains the primary operational alternative if mixing barite at surface is delayed, allowing immediate circulation to prevent gas migration and downhole barite sag.

6.2 Recommendations

- Personnel Certification: Mandate active International Well Control Forum (IWCF) or WellSharp certification for all rig crew personnel.
- Leak-Off Testing (LOT): Perform an accurate Leak-Off Test immediately after drilling out the 9-5/8" casing shoe at 6,800 ft to confirm formation fracture margins.

- BOP Maintenance: Conduct function and pressure tests on the BOP stack every 14 days and after every casing string installation.
- Tripping & Swabbing Controls: Maintain controlled tripping speeds and monitor trip tank volumes using "fingerprinting" techniques to prevent swab-induced kicks.
- Barite Stock Inventory: Maintain sufficient bulk Barite stock on site at Well 6P2-59 to rapidly weight up active pits from 10.0 ppg to 13.20 ppg.
- Flow Checks: Perform mandatory flow checks upon encountering any drilling rate break, torque change, or pit volume anomaly.

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Compliance with ethical standards

Disclosure of conflict of interest

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